Run II Collider Report

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Users' Meeting

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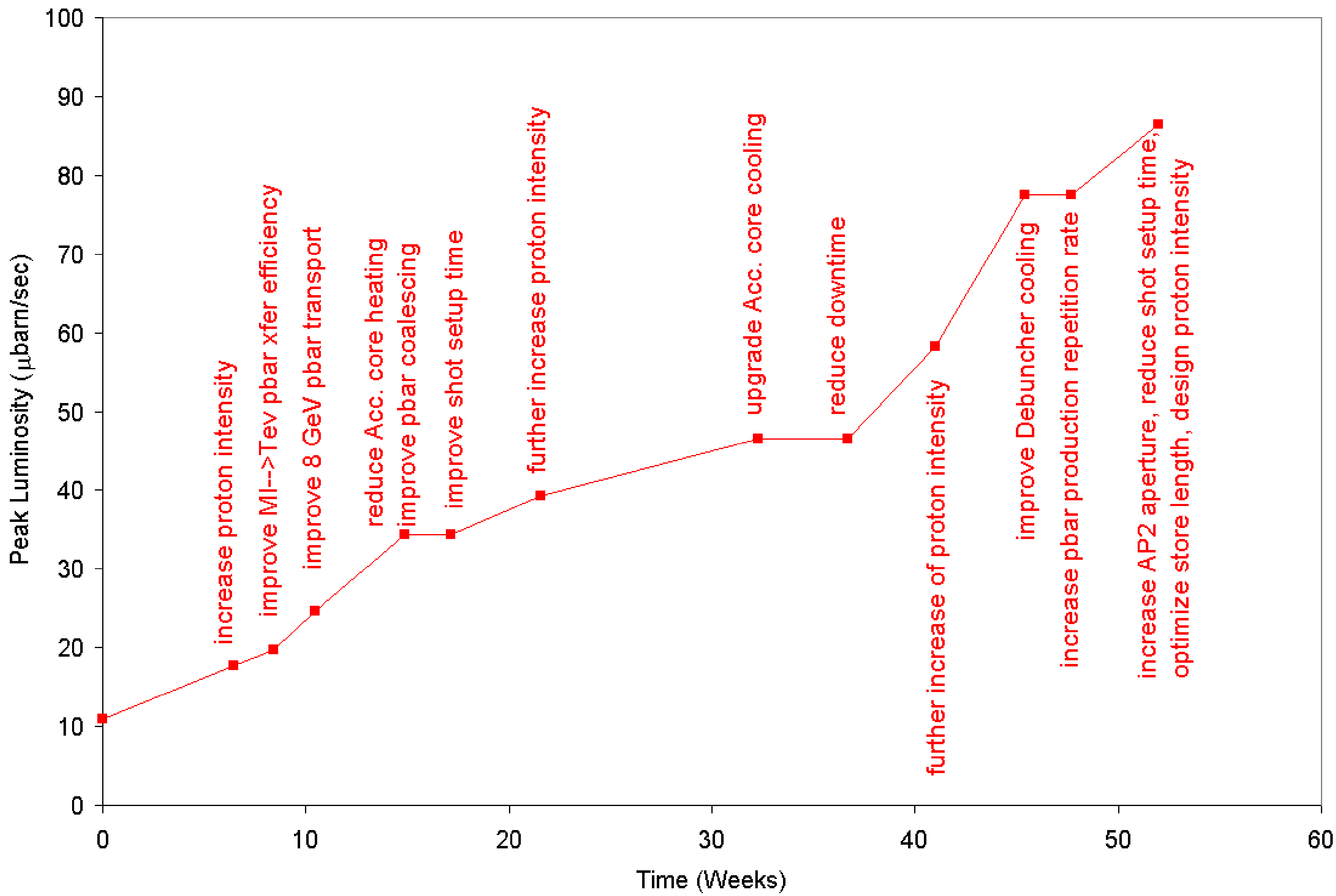
Collider Goals

- The primary goal for the TEVATRON Collider in calendar year 2002 is to achieve:
  - A peak luminosity of 86×10^{30} cm^{-2} sec^{-1}
  - Integrate 300 pb^{-1}
- The goal for 2003 is to:
  - integrate the Recycler into operations
  - Push for a peak luminosity of 120×10^{30} cm^{-2} sec^{-1}
- The goal for 2004 is to:
  - Make antiproton recycling operational
  - Push for a peak luminosity of 220×10^{30} cm^{-2} sec^{-1}
  - Begin installation of the Run IIb upgrades
- The goal for 2005 and beyond is to:
  - Achieve a peak luminosity of 410×10^{30} cm^{-2} sec^{-1}
- This talk will look at the performance of the TEVATRON Collider during the first 5 months of 2002

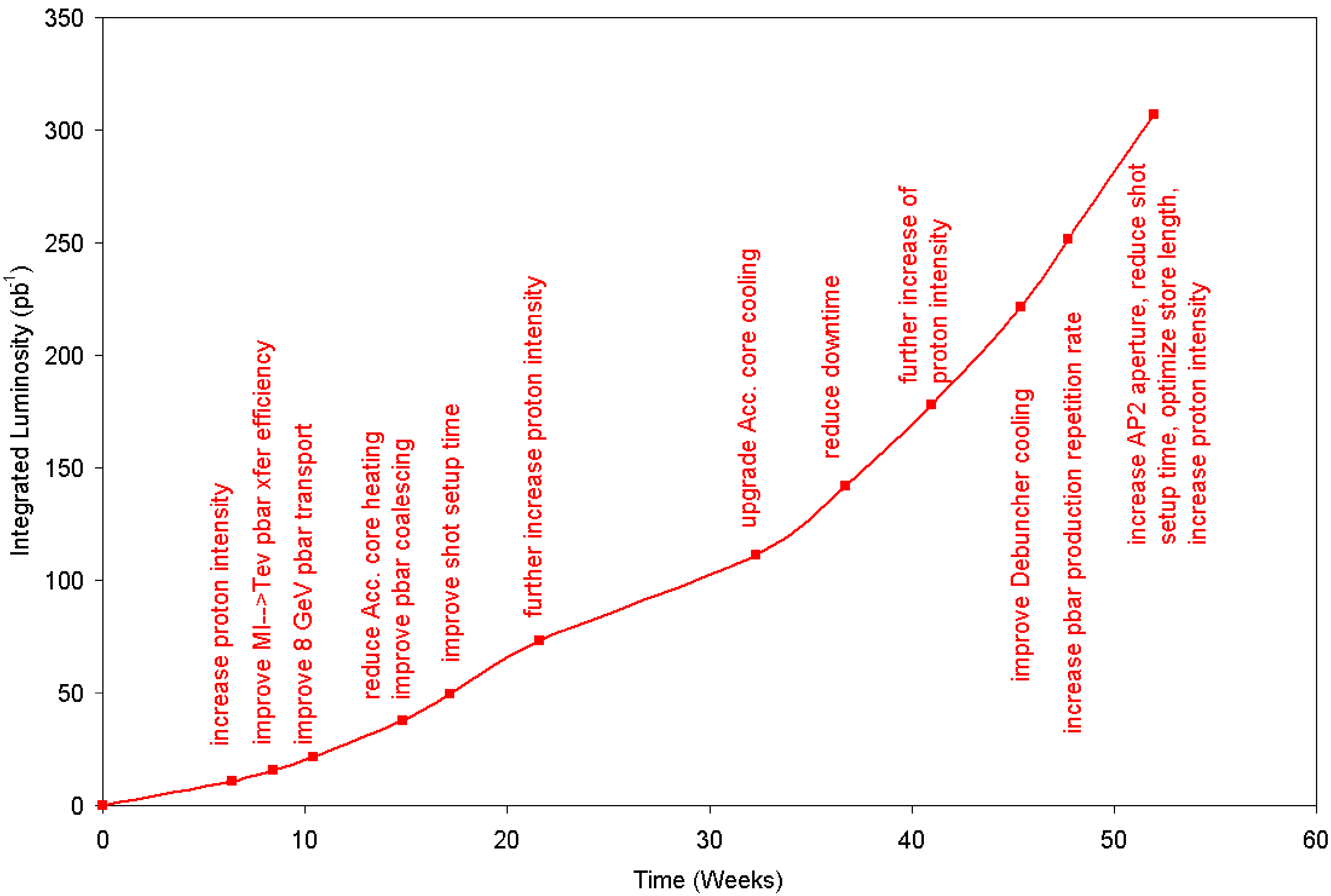
The Church Plan

Peak Luminosity



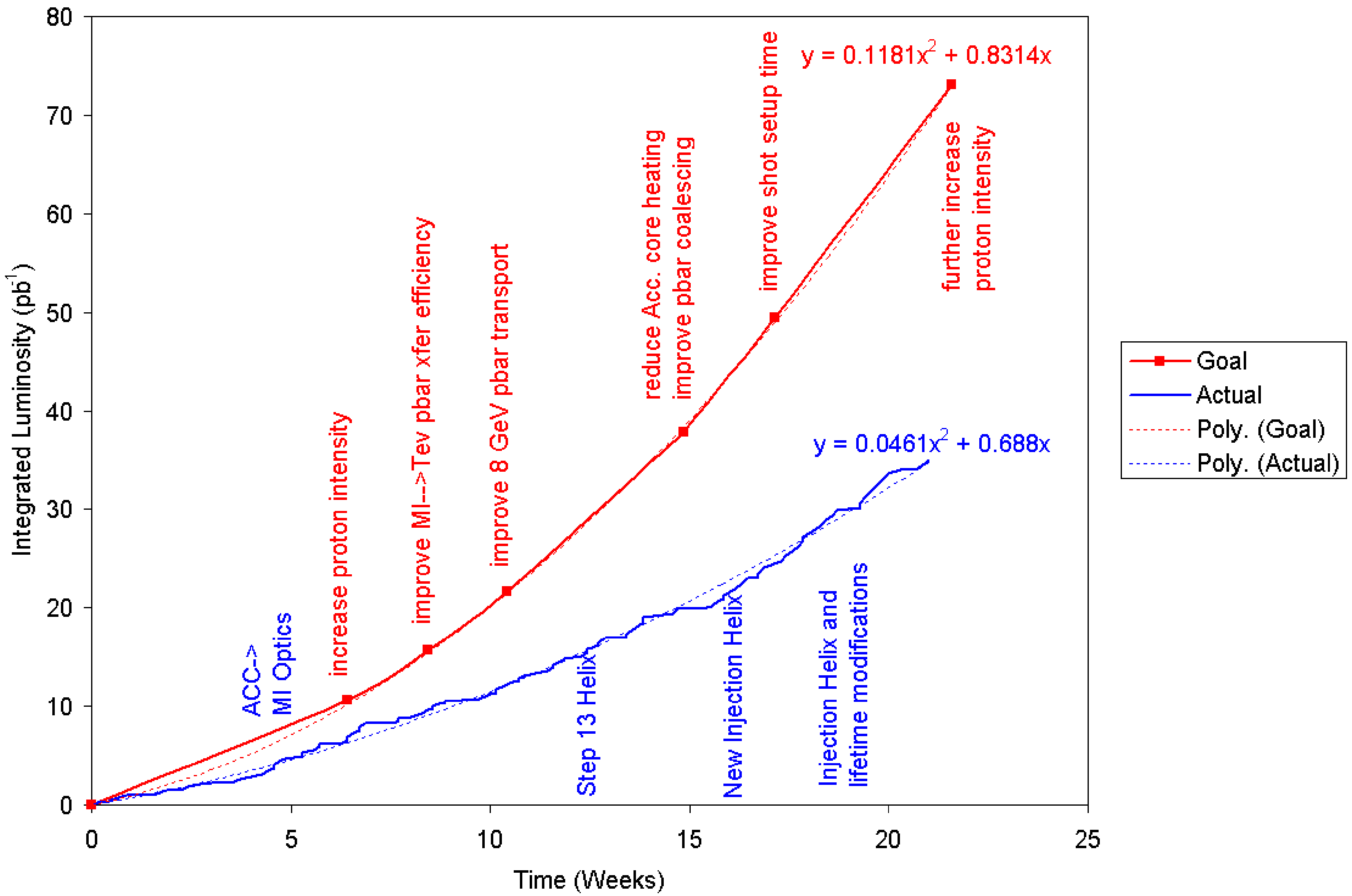
The Church Plan

Integrated Luminosity

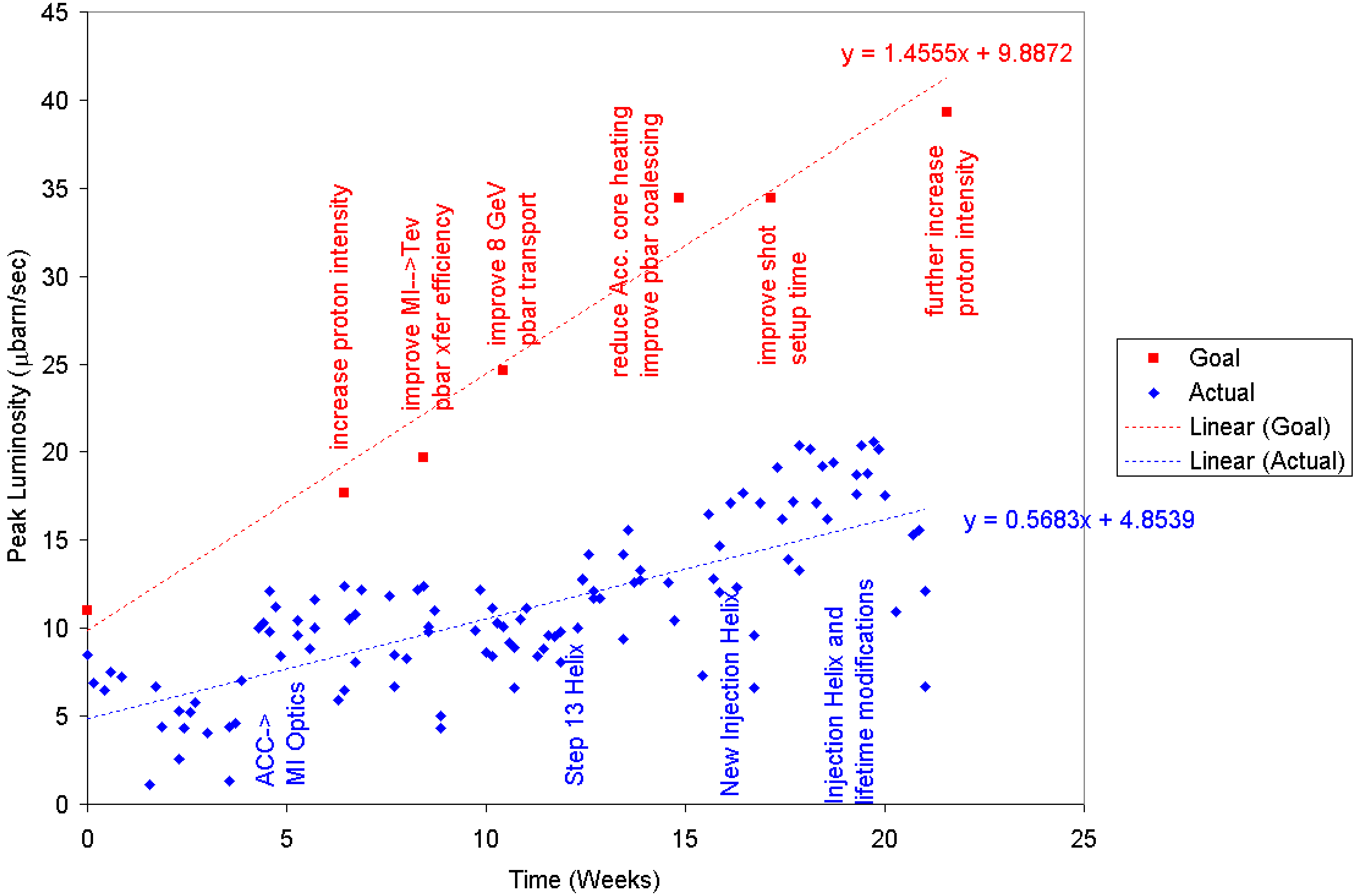


Integrated Luminosity

Goals vs. Reality



Peak Luminosity

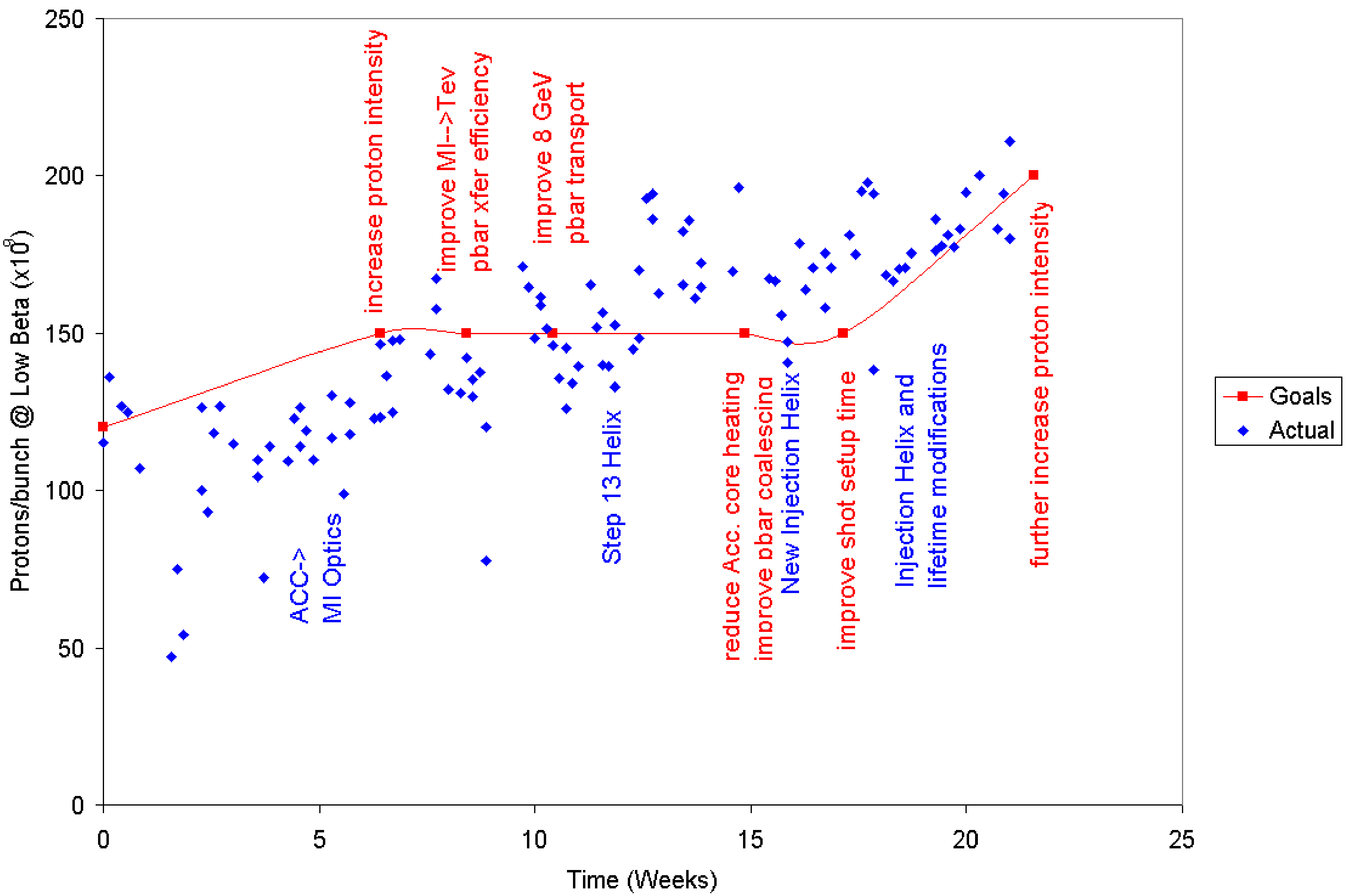


Luminosity Recipe

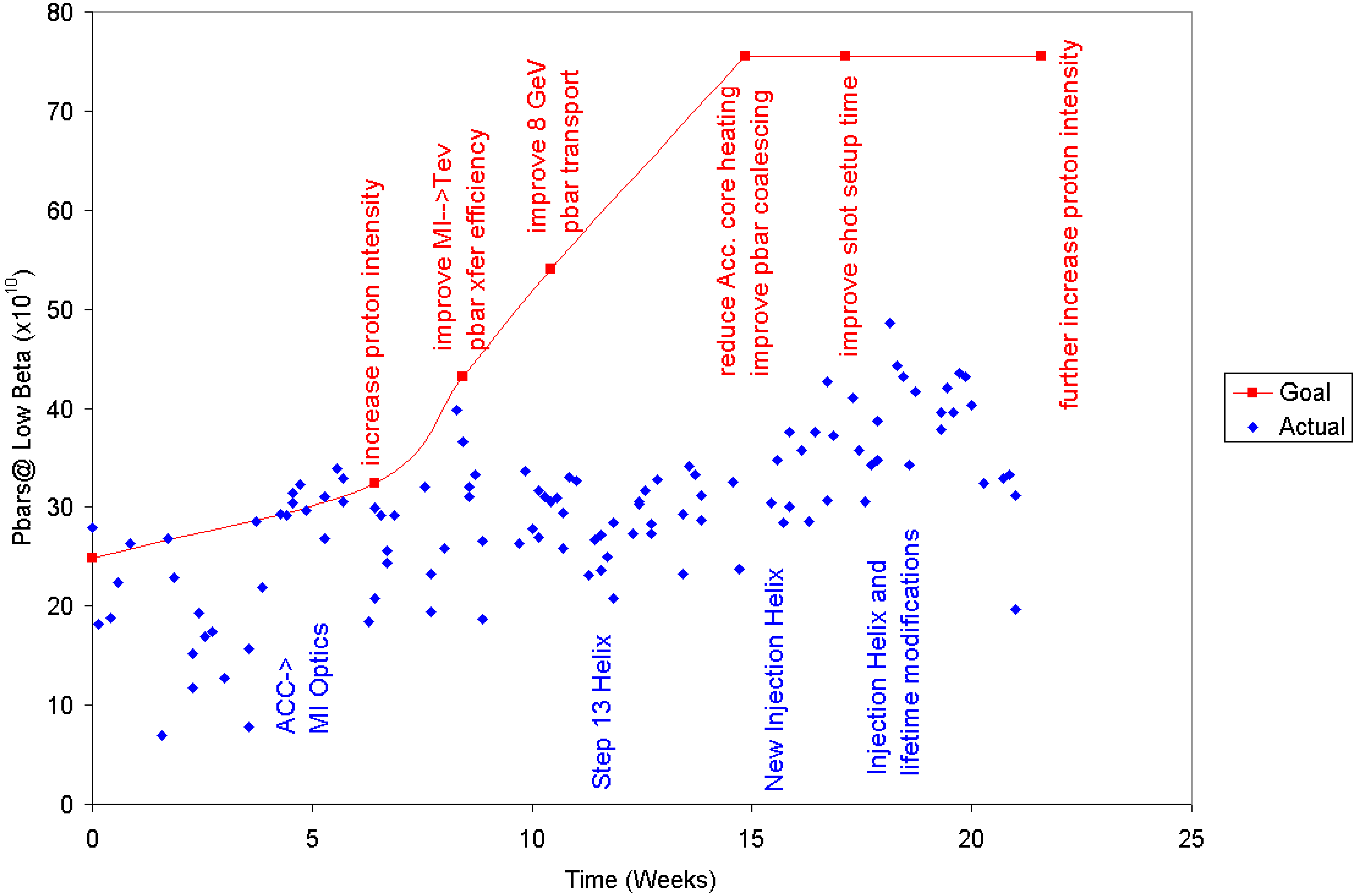
$$L = \frac{3\gamma f_0}{\beta^*}\left(BN_{\bar{p}}\right)\left(\frac{N_p}{\varepsilon_p}\right)\frac{F\left(\beta^*, \theta_{x,y}, \varepsilon_{p,\bar{p}}, \sigma^L_{p,\bar{p}}\right)}{\left(1+\varepsilon_{\bar{p}}/\varepsilon_p\right)}$$

- The major luminosity limitations are:
  - The number of antiprotons (BN_{pbar})
  - The proton beam brightness (N_p / ε_p)
  - Hour glass factor ($F < 1$)

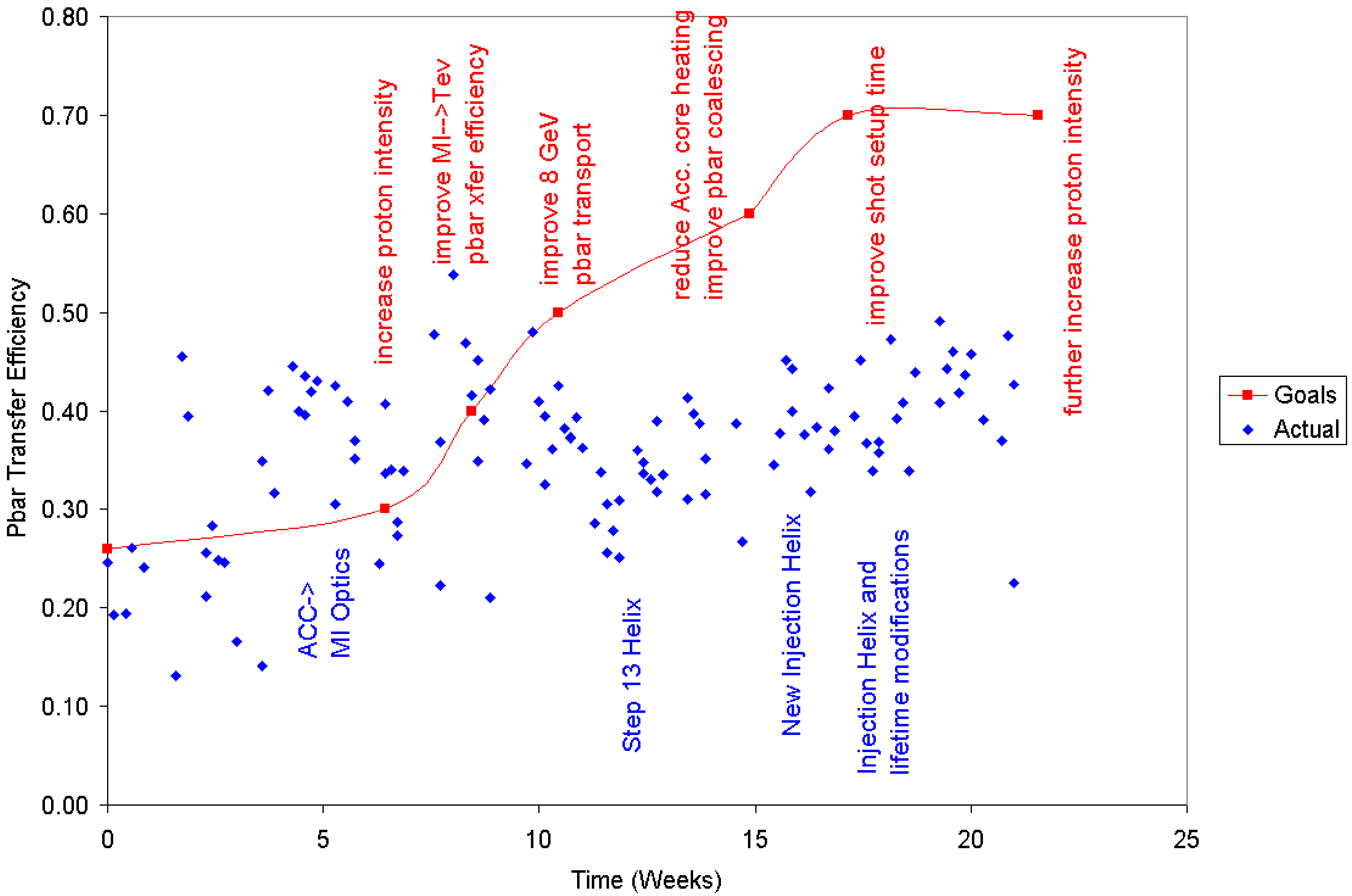
Protons/bunch at Low Beta



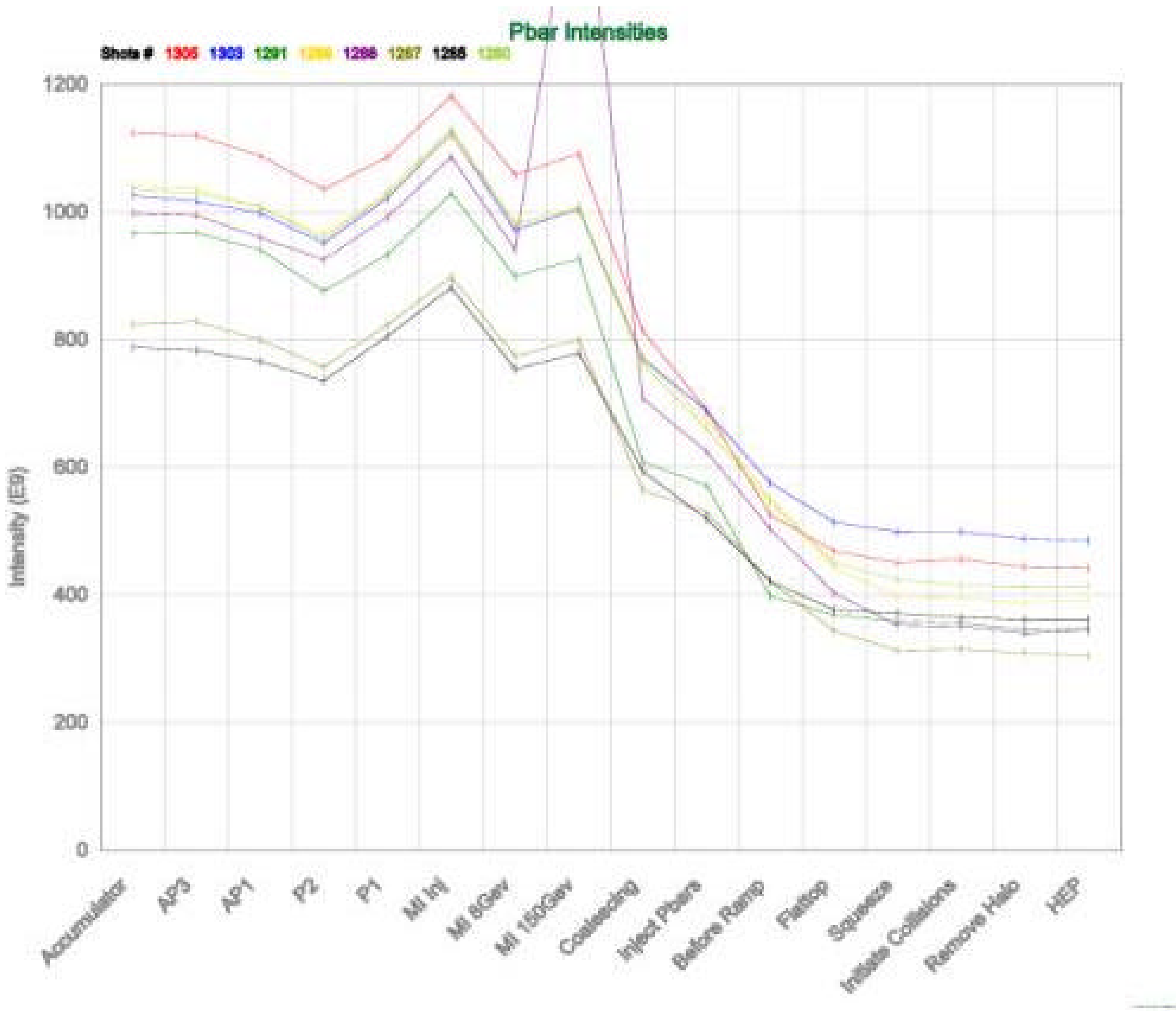
Total Number of Pbars at Low Beta



Pbar Transfer Efficiency to Low Beta



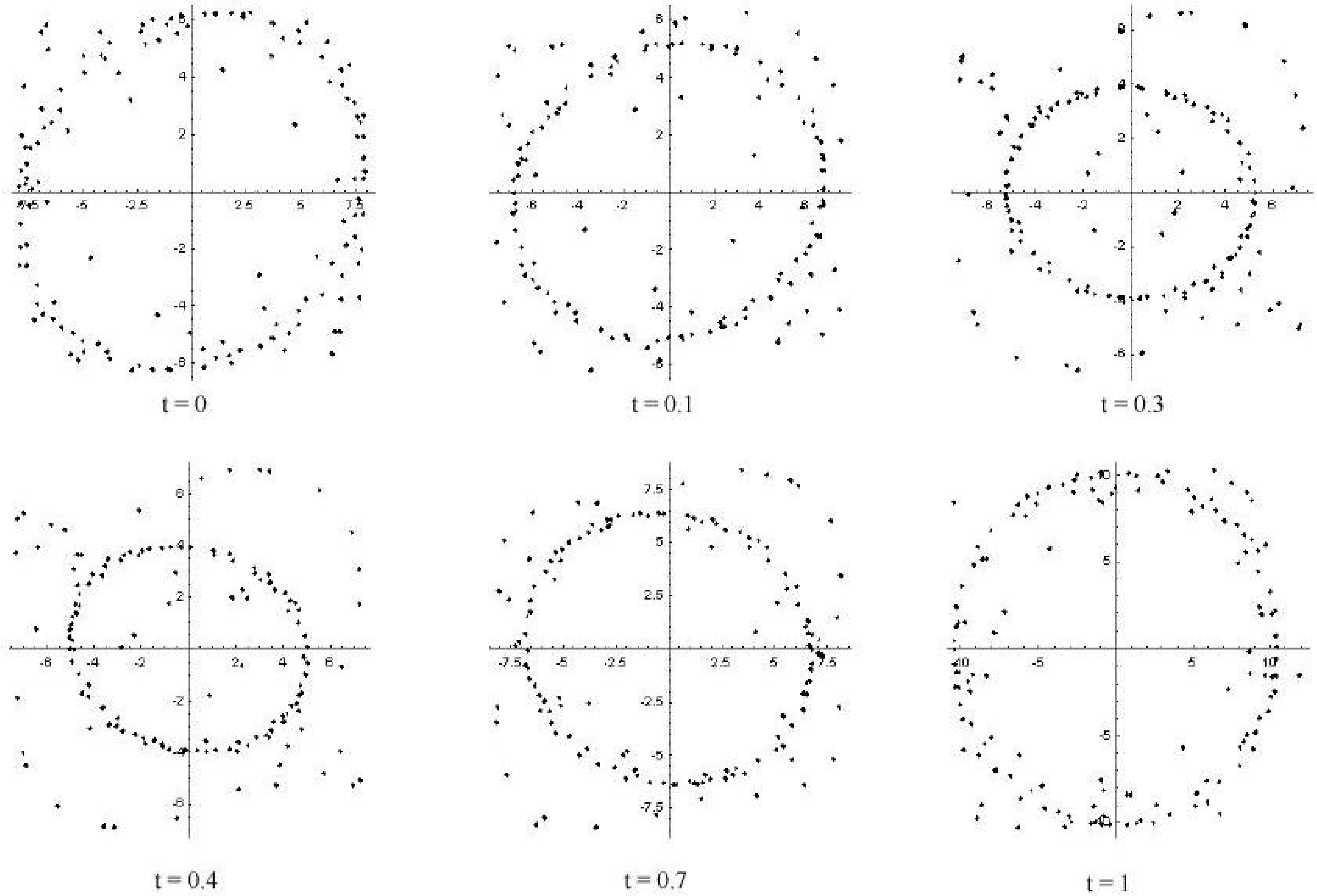
Pbar Transfer Efficiency to Low Beta



Beam Separation in the TEVATRON

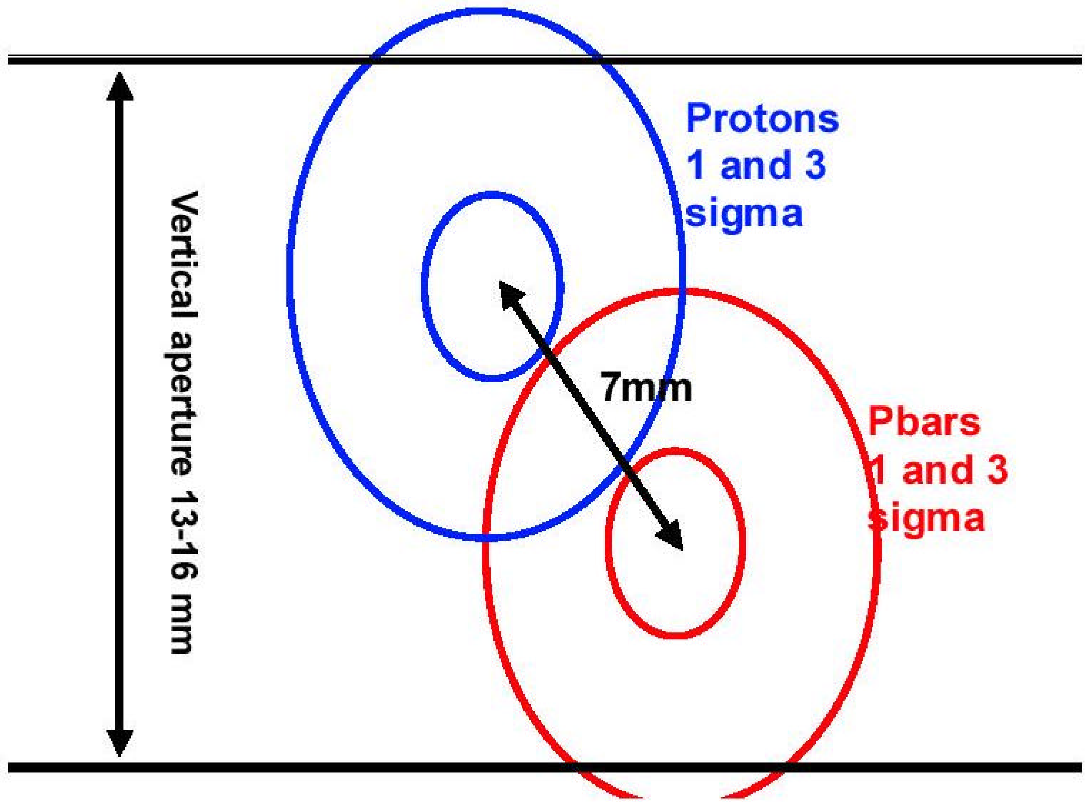
- With 36 bunches there are a much greater number of “long range” crossings
- The proton beam acts as a “soft” collimator to the pbar beam if the beam separation is too small (<2.5-3σ)
  - Original beam-beam calculations focused on tune shifts on the collision helix
  - Dynamic aperture effects due to long-range interactions are now thought to be a much more serious problem.
    - Dynamic aperture calculations are very difficult to do and interpret.
    - The beam goes around 10 million turns every 3 minutes
- Solution
  - Better helices
    - Location constraints
    - Lattice constraints
    - Hardware constraints
  - Bigger aperture (needed for bigger helices)
  - Smaller beams
    - Smaller source emittances
    - Smaller emittance dilution through the accelerator chain.

Better Helices in the TEVATRON



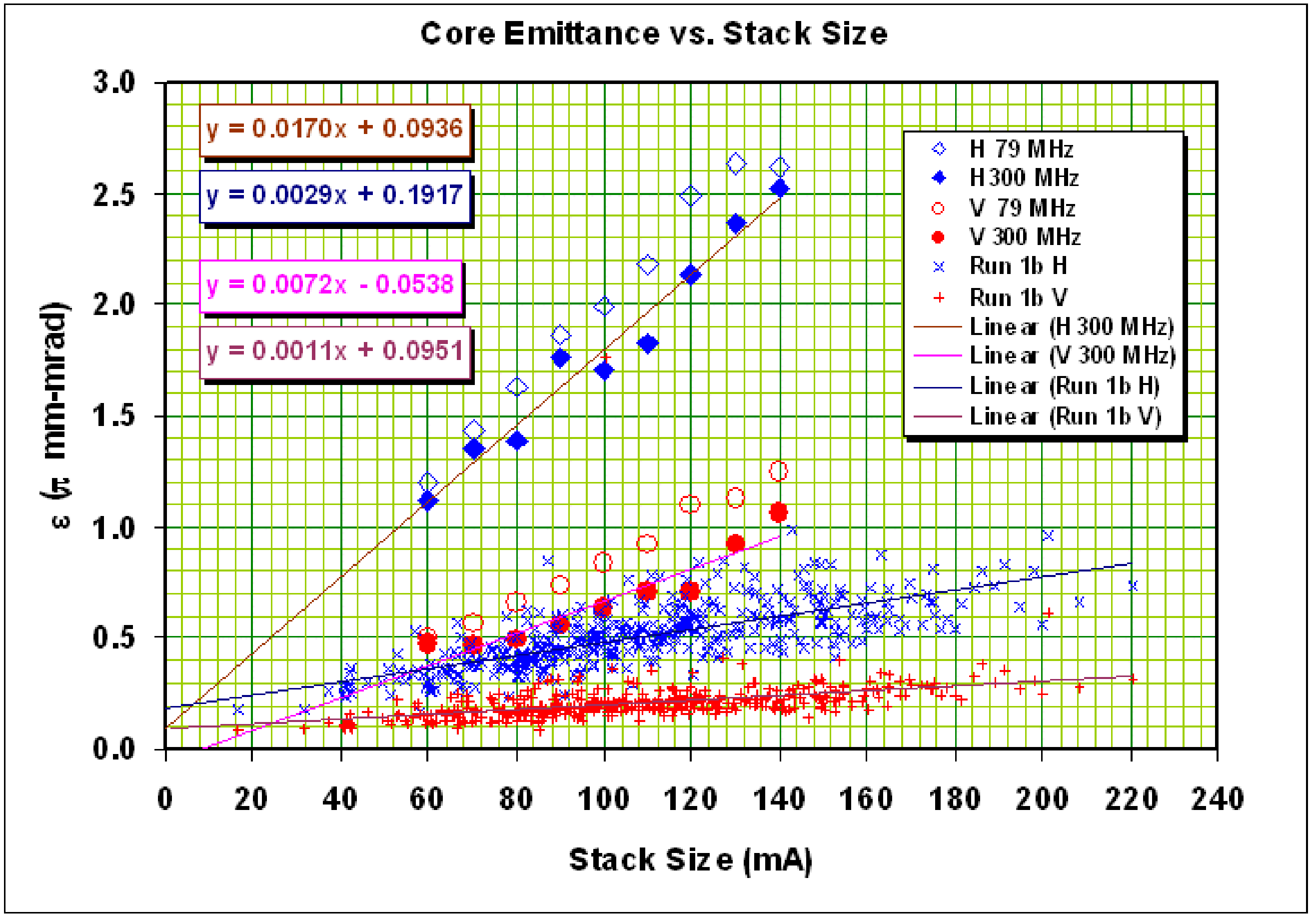
- Normalized separations at all possible collision points during the “old” Step 13 -> Step 14 collision cog
  - With beams separated at 1.8σ, a ~20% beam loss occurred
  - With beams separated at 2.7σ with new helices, beam loss is removed

Bigger Aperture in the TEVATRON



- CO Lambertson Aperture restriction
  - The “tilting” of the helix is limited due to separator constraints
  - The C0 Aperture will be increased during the Fall 2002 shutdown.
    - New magnets
    - Beam separation can increase by ~30%

Pbar Beam Size



- The horizontal emittance of a typical 100E+10 antiproton stack is about a factor of 2 larger than the Run II handbook design value.

Pbar Beam Size

- We believe that the horizontal emittance growth is caused by
  - Intra-beam scattering (60%)
  - Trapped ions (40%)
- The intra-beam scattering (IBS) heating of the beam is worse now for Run II than it was in Run I because of the changes in beta functions that were the result of the Accumulator Lattice Upgrade
- The Accumulator lattice was changed to handle the anticipated factor of 3 increase in pbar flux due to the Main Injector Project.

Cooling Bandwidth increased 2x

Slip factor changed by lattice to keep cooling system stable

Stack Rate

$$\Phi = \frac{W^2 \eta E_d}{f_0 p \ln\left(F_{\min}/F_{\max}\right)}$$

- The change in η caused the IBS heating term to be a factor of 2.5x larger in Run II than for Run I

Pbar Beam Size

- We have developed a two-fold plan to reduce the transverse emittance:
  - Better transverse stochastic cooling of the Accumulator core.
    - The bandwidth will increase by a factor of 2
    - The center frequency of the band will increase by a factor of 1.5
  - Dual lattice operation mode of the Accumulator
    - Keep the "stacking" lattice (η=0.012) for pbar production
    - During shot setup, ramp the lattice with the beam at the core orbit to the "shot" lattice (η=0.022)
      - The "shot" lattice will reduce the intra-beam scattering heating by a factor of 2.5
      - The "shot" lattice will increase the cooling rate by a factor of two increase in mixing due to the change in η

$$\frac{d\varepsilon}{dt} \approx -\frac{\varepsilon}{\tau_{cool}} + \frac{\text{Heat}}{\varepsilon^{3/2}}$$

Center freq.

Ions

IBS

$$\frac{\varepsilon_{old}}{\varepsilon_{new}} = \left(\frac{\tau_{cool_{old}}}{\tau_{cool_{new}}} \frac{\text{Heat}_{old}}{\text{Heat}_{new}} \right)^{2/5} = \left(2 \times 1.5 \times 2\right)^{2/5} \times \left(\frac{0.4 + 0.6}{0.4 + \frac{0.6}{2.5}} \right)^{2/5} = 2.4$$

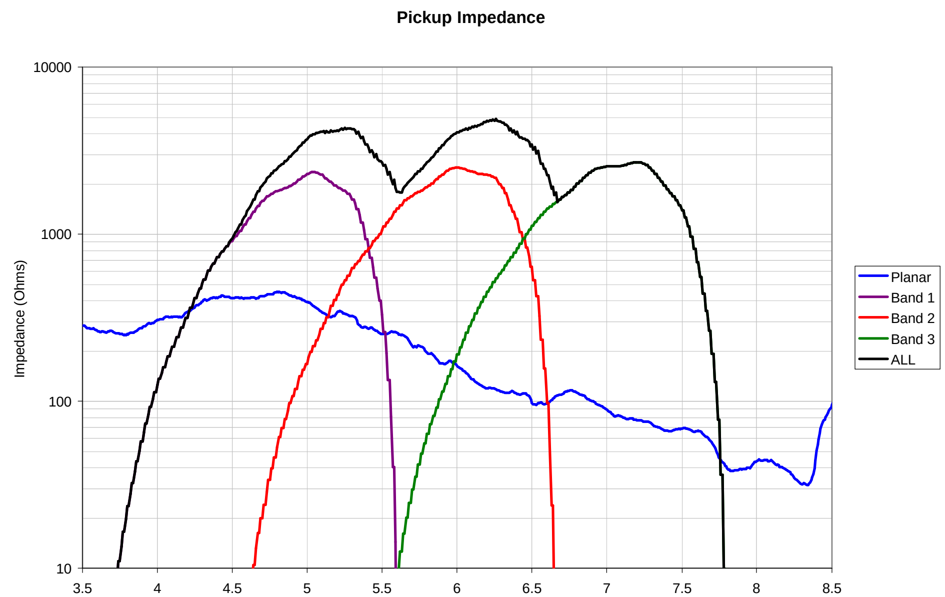
Bandwidth

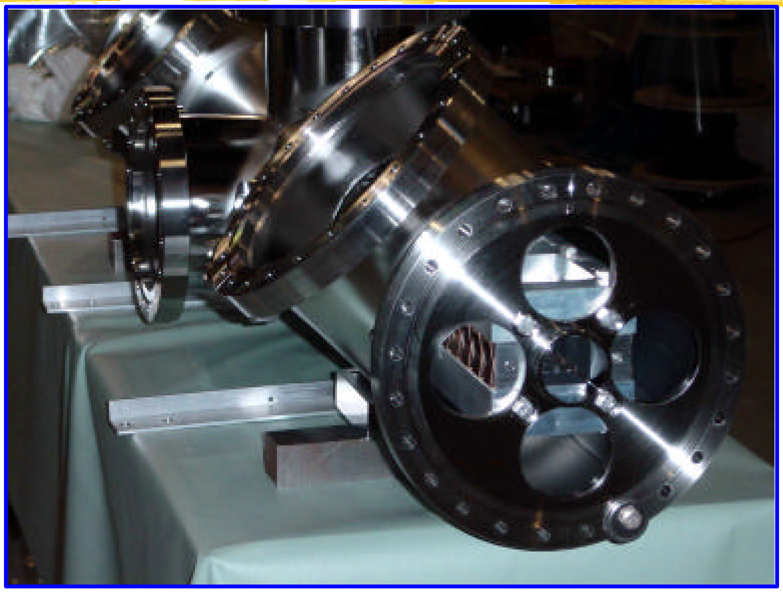
Better Mixing

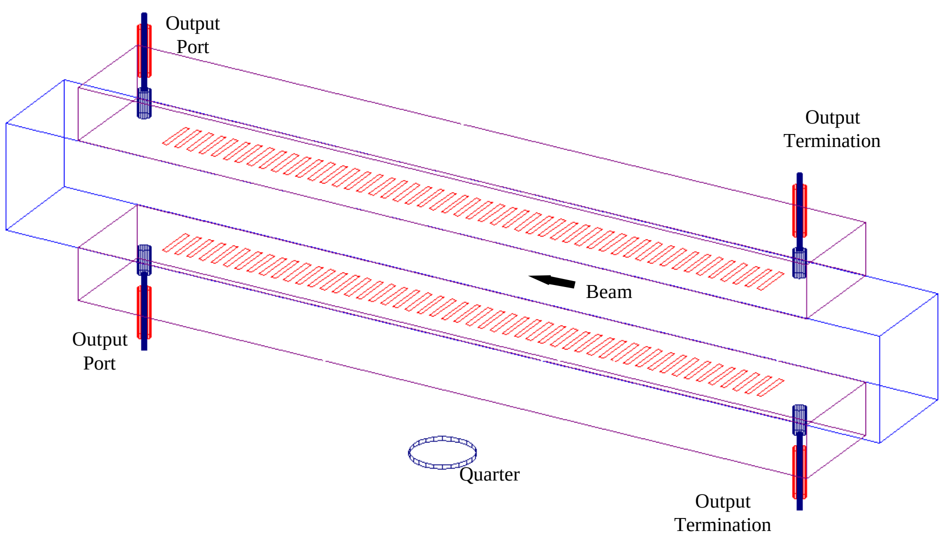
Reduced IBS

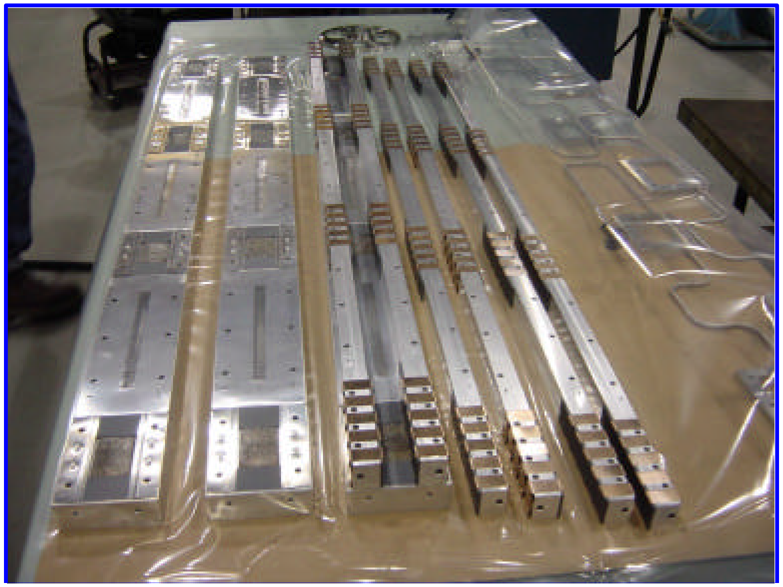
Accumulator Core Cooling Upgrade

(based on Debuncher-style Technology)

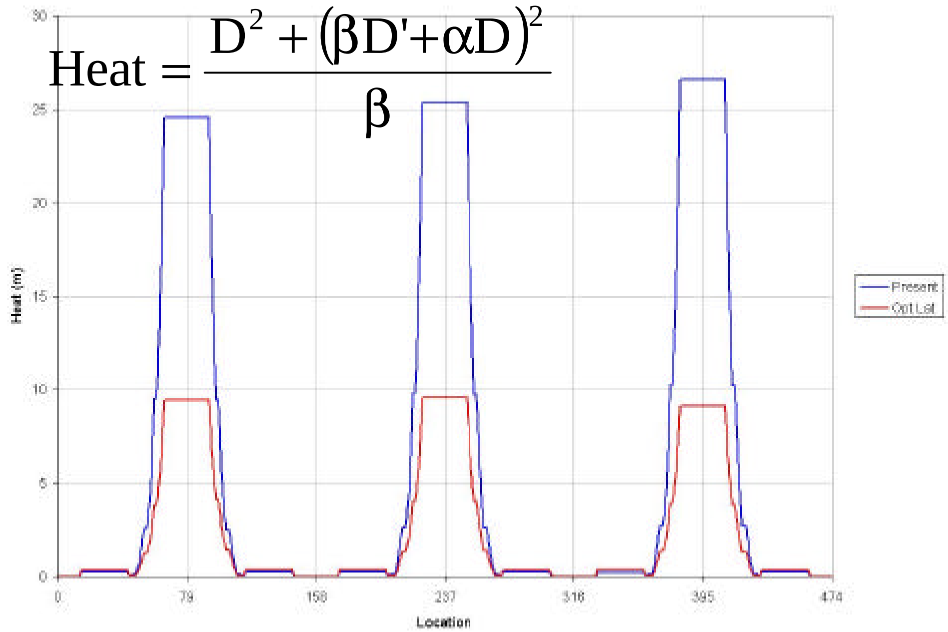




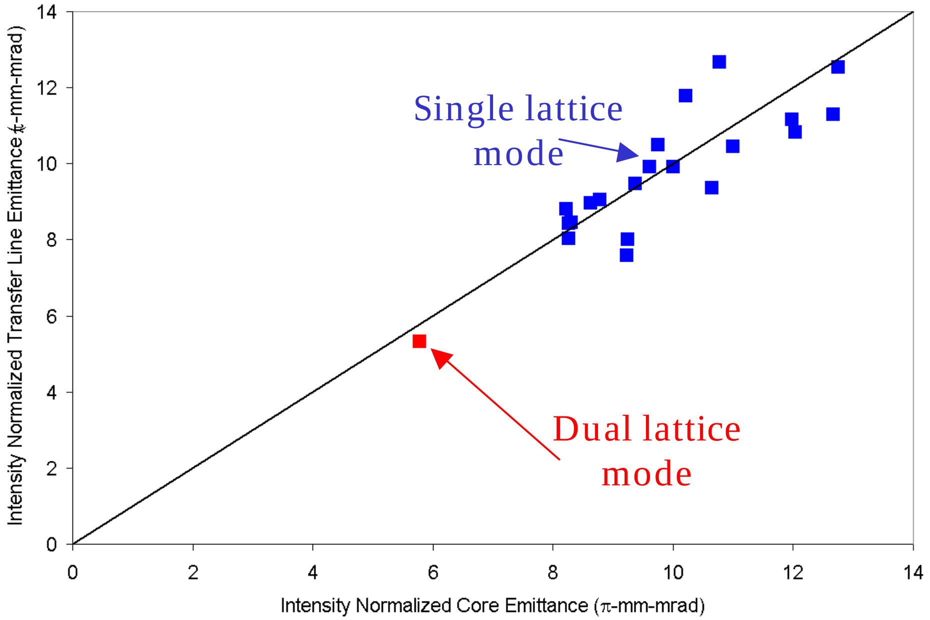




Accumulator Dual Lattice Operation



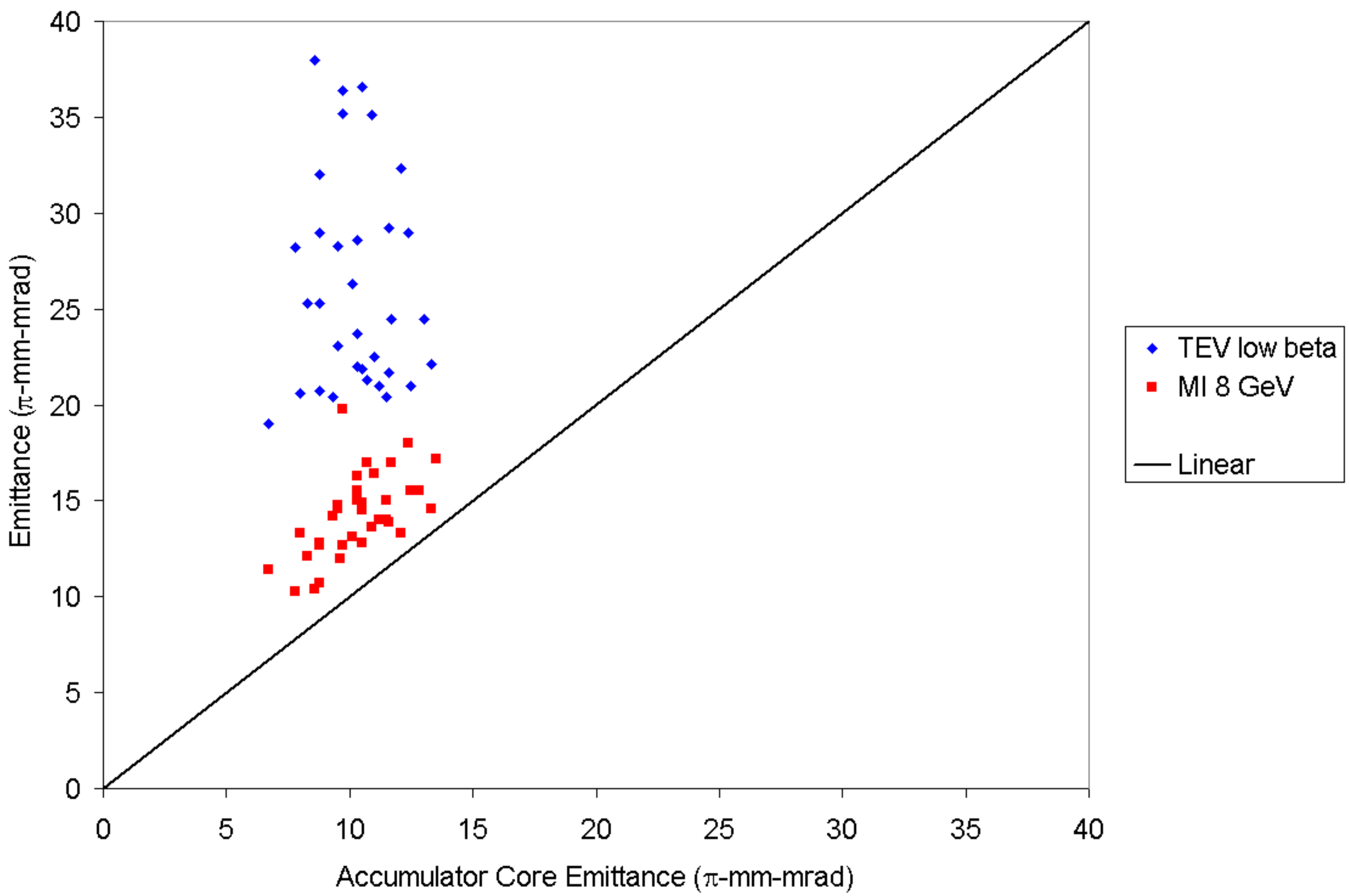
$$\text{Heat} = \frac{D^2 + (\beta D' + \alpha D)^2}{\beta}$$



- A new shot lattice was designed and commissioned
- Ramps between the stacking lattice and the shot lattice were commissioned
  - 100% efficient in beam intensity and beam size.
- The 3rd to last shot before the shutdown was done with the ramping lattice mode.
  - The pbar emittance in the core and the 8 GeV transfer line was substantially reduced for this shot.
  - The ramping lattice mode was not used for the last 2 shots because of “operational” problems

Pbar Emittance Dilution Throughout the Accelerator Chain

- Transfer line orbit mismatches
- Transfer line lattice mismatches
- Emittance dilution during acceleration
  - Resonances
  - Heating mechanisms – noise, IBS, etc…



Other Issues

- Poor proton lifetime at 150 Gev
  - Gas scattering
- Proton longitudinal instabilities in the TEV
- Proton transverse instabilities in the TEV
  - Requires large chromaticity
  - tightens tune working space
- Detector background (vacuum?)
- DC Beam in the TEV
  - Leakage out of RF Bucket – RF Noise
- Coalescing in the Main Injector
  - Contributes to poor 150 GeV lifetime because of momentum aperture
  - Reduces luminosity because of the “hourglass” effect
- Pbar stacking rate

Summary

- The present major limitation to luminosity is the poor transmission efficiency of antiprotons to low beta.
- The major culprit in the poor transmission efficiency is long-range effects in the TEVATRON
- The plan to mitigate the long-range effects is to improve beam separation in the TEVATRON
  - Improved helices
    - This has been the major contribution to increasing luminosity over the past couple of months
  - Improved TEV aperture
  - Smaller antiproton emittances
    - Accumulator Core cooling
    - Dual lattice mode in the Accumulator
    - Antiproton injection damping into the Main Injector and TEVATRON
    - Improved transfer line matching

Key Projects for 2002

- Install new Accumulator core cooling system – June
- Improve TEV F0 vacuum - June
- Commission Accumulator dual lattice mode – July
- Commission Main Injector Pbar Injection Dampers - July
- Modify operations to minimize time spent at 150 GeV in TEV – 24 min. -> 9 min. – August
- Build, install, and commission TEV transverse dampers – September
  - Injection
  - Instability
- Remove C0 aperture limitation – open helix by 30% - October
- Modify A0 straight section to improve helix – October

Run 2B

- The Run 2B report was finished December 2001 and reviewed by the Accelerator Advisory Committee.
  - This report will serve as the basis for a TDR
  - A finished technical design report for Run 2b still does not exist.
- The project consists of 7 sub-projects
  - Slip Stacking – minimal manpower (0.5 – 1 FTE)
  - Lithium Lens Upgrade – in progress
  - AP2-Debuncher Upgrade – on hold
  - Accumulator Stacktail Upgrade – on hold
  - Antiproton Transfer Upgrade – on hold
  - Recycler Electron Cooling – in progress
  - TEVATRON electron lens – in progress
- A number of these projects are progressing at a very slow rate because manpower is being concentrated on Run 2A

Run 2B and the Recycler

- The peak luminosity goal for Run 2B is 4.1×10^{32} cm^{-2}-sec^{-1}
- At this rate, the collider will consume antiprotons in collisions at a rate of 20×10^{10} hr^{-1}
  - We will need to stack pbars at 60×10^{10} hr^{-1}
    - Our present peak rate is 11.2×10^{10} hr^{-1}
    - Our Run 2A goal is 18×10^{10} hr^{-1}
    - To obtain 60×10^{10} hr^{-1} , we will have to modify the Accumulator stacktail system.
    - For stability reasons, the peak stack of this modified stacktail system will be about 20×10^{10} pbars.
  - We will need to accumulate 1000×10^{10} stacks.
- The Recycler is a must for Run 2B !!

Run 2B and the Recycler

- Recycler progress:
  - All stochastic cooling systems have been commissioned
  - Cooled beam lifetime is 100 hours at 20×10^{10} pbars
    - Compared to 1200 hours at 90×10^{10} pbars for the new Accumulator shot lattice
  - Asymptotic emittance is 8 π-mm-mrad at 20×10^{10} pbars
    - Compared to 6 π-mm-mrad at 80×10^{10} pbars for the new Accumulator shot lattice
  - Antiproton injection efficiency is low (40-50%)
- During the Fall 2002 shutdown
  - The number of ion pumps will be doubled.
    - Improve lifetime
    - Improve asymptotic emittance
  - More shielding and ramped correctors will be added to combat the tune modulation during Main Injector Ramps
- Electron cooling is scheduled to be installed in 2004